DESIGN CONSIDERATIONS, INSTALLATION AND OPERATION OF THE TWO-STAGE PARALLEL FLOW ABSORPTION CHILLER

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ABSTRACT

This presentation describes the actual design consideration and field operation experience of two-stage parallel flow absorption chillers. The applications include new construction, rehabilitation of old HVAC systems, cogeneration, and industrial process heat recovery.

The high performance (COP = 1.14), and reduced maintenance cost of the two-stage parallel flow absorption chiller provides a notable improvement over the conventional single stage absorption chillers (COP = .6). The infamous reputation of the single stage absorption chiller for crystallization, poor mechanical performance, and general unreliability has been completely neutralized by new design concepts incorporated in the two-stage parallel flow absorption chiller/heater. The ease of maintenance and virtual elimination of crystallization has vastly improved chilled water production and mechanical longevity.

The two-stage parallel flow absorption chiller is adaptable to various heat sources including direct fired multi-fuel, steam, exhaust, hot water, thermal fluids, etc. This makes this chiller a worthy consideration as an alternate to electrically driven refrigeration.

The two-stage parallel flow absorption chiller has been operating in the United States since 1979 and there is presently over 24,000 tons of installed capacity on line. Installations include office buildings, hospitals, computer centers, industrial process water and others.

INTRODUCTION

When fuel was cheap and plentiful prior to 1973, absorption air conditioning represented 40% of the large tonnage (100 tons and up) market in the United States. As the cost of fossil fuel increased, the operating economy of these relatively inefficient single stage absorption chillers decreased until most of them have now been replaced by other equipment.

Absorption chillers today represent less than 10% of the market in the United States but in Japan, absorbers enjoy over 70% of the large tonnage market. The reason for the high market acceptance of absorption chillers in Japan is the use of the highly energy efficient two-stage, parallel flow absorber.

The two-stage parallel flow chiller discussed herein has been specifically designed to optimize energy efficiency, maintain operational integrity and be compact in size for easy installation, service and repair. No longer are building owners and operators tied to the purchase of electricity for the sole source of air conditioning.

OPERATION

Until recently, it was necessary to have low pressure (15 psig) steam or hot water to produce the state-of-the-art absorption air conditioning. If steam were available from a waste or heat recovery source, then the consideration of absorption air conditioning may still be viable. If, on the other hand, fuel had to be burned in a boiler or heater to produce the heat for the absorption chiller then the cost would be too great. The single stage absorption chiller requires approximately 17,000 to 20,000 Btu's per ton (net). If a boiler having efficiency of 80% is used, then the gross fuel input is equivalent to approximately 25,000 Btu's per ton. This compares to the heat input required for the two-stage parallel flow absorption chillers which is approximately <u>11,000 Btu's per ton</u> or a gross savings of over 50%. The coefficient of performance (COP) for the two-stage parallel flow chillers varies from 1.21 for the high efficienty steam models, down to 1.1 for the direct fired models.

The lithium bromide reaction in both the older single stage chiller and the new two-stage parallel flow chiller is the same. The lithium bromide has a lower saturated vapor than the refrigerant (water) at a lower temperature than itself. This interaction is called "hygroscopic attraction." The lithium bromide literally <u>absorbs</u> the cool water vapor: therefore the <u>name absorption chiller</u>.

In the two-stage parallel flow chiller, primary heat is applied to the first stage generator (Fig. Zone 2), to bring the temperature of the diluted lithium bromide solution up to approximately 300 degrees F. at which point the refrigerant vapor (water) is driven off at a temperature of approximately 195 degrees F. The high temperature water vapor is then directed to the second stage of the chiller where it is cooled and condensed (Fig. Zone 3). The latent heat of vaporization from the refrigerant vapor as well as the sensible heat is absorbed in the second stage of the chiller. The hot water vapor given off from the second stage is then condensed by cooling tower water flowing through the condenser tubes (Fig. Zone 4), and mixes with the cooled condensate from the first stage.

The condensed refrigerant now at approximately 105 degrees F. flows from the condenser section of the chiller through an expansion valve and into the evaporator section at a temperature of 39 degrees F. The refrigerant pump circulates the chilled refrigerant through specially designed spray nozzles over the evaporator tubes (Fig. Zone 6). The system heat is absorbed from the evaporator tubes and increases

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the heat of the refrigerant causing vaporization.

In the meantime, the concentrated lithium bromide solution from the first and second stage generators has been passed through a heat exchanger (Fig. Zone 1), to lower the temperature and then passed through spray nozzles over the absorption coils (Fig. Zone 6). The cooled lithium bromide absorbs the water vapor coming from the evaporator section, becomes diluted, and is stored in its diluted stage in a reservoir at the bottom of the chiller shell.

A significant contributor to the efficiency of the two-stage parallel flow chiller is the two section counter flow heat exchanger. One section flows solution to and from the first stage generator while a separate yet contiguous section flows solution to and from the second stage generator. The cooled diluted solution from the absorber section of the chiller is passed in a counter direction to the hot concentrated solution coming from the first and second stage generators. This preheats the diluted solution prior to its being pumped into the first and second stage generator. The hot concentrated solution from the generator is cooled by the diluted solution before being directed into the absorber section of the chiller for final cooling and dilution. The counter flow heat exchanger is fabricated by having tubes containing the hot concentrated solution run inside of the tubes carrying the cooler diluted solution in the opposite direction. The maximum efficiency of the counter flow heat exchanger approaches 100% as opposed to a maximum efficiency of the conventional cross or counter flow heat exchanger of only 60%. These shell and tube cross and counter flow heat exchangers are commonly used on the single stage absorbers. Because the solution pump directs the diluted solution into both the first stage and second stage simultaneously, the name PARALLEL FLOW has been used.

Because of the parallel flow and the other significant efficiencies in the chiller shell itself, the two-stage parallel flow chiller is designed to operate significantly apart from the crystallization curve for lithium bromide. This operational design virtually eliminates crystallization problems which have plagued earlier single stage chillers as well as the more recent series flow two-stage absorption chiller.

DESIGN AND INSTALLATION

The two-stage parallel flow absorption chiller has been specifically designed to take advantage of all of the positive attributes of absorption air conditioning while eliminating or minimizing past problems. The most significant difference is the efficiency of the new two-stage parallel flow absorption chiller. With COP's ranging up to 1.21, a great deal of economic as well as energy resources can be saved.

The energy or fuel input to the two-stage parallel flow chiller can vary widely. The most prevalent model is the direct fired configuration. This configuration utilizes a multi-fuel, low excess air burner which can utilize most gaseous fuels, but primarily natural gas, as well as alternate liquid fuels up to and including #2 furnace oil. This means that in cases where emergency air conditioning may be required, the chiller can operate on the same emergency fuel used for the emergency generator. This is certainly a consideration for computer installations, emergency shelters, hospitals, etc. The fuel rate is approximately 11 cubic feet of gas per ton/hour when considering the annual operating efficiency of the system. The specific fuel consumption of the two-stage parallel flow absorption chiller actually improves as load drops from 100%. The average fuel consumption is for all practical purposes constant from 100% load down to 20% load (5 to 1 turndown).

The next most prominent heat input for the two-stage parallel flow chiller is hot exhaust gas. It is referred to as the cogeneration model. This configuration utilizes hot gas from a gas turbine, internal combustion engines, or process flow to provide the energy to the first stage generator. There are a number of installations currently operating in Southern California where the exhaust from gas turbines is being taken directly into the two-stage parallel flow chiller. In such cases the overall recoverable heat from the system is approximately 40% greater than is accessible from the use of the old single stage chiller using low pressure steam from a heat recovery boiler.

Steam at approximately 115 psig can also be used in these two-stage parallel flow chillers. The standard steam chiller has a heat input of 10.56# per Ton-Hour (115 psig). There is a high efficiency steam model available that has a heat rate of 9.9# per Ton-Hour (COP = 1.21).

Hot water, thermal fluids, and other heat sources can also be considered as prime energy input for specifically designed chillers.

A significant design feature of the two-stage parallel flow chiller is that it can also be a heater. The hot refrigerant gas coming off of the first stage generator can be passed into a shell and tube condenser rather than having it all go into the absorber shell. If system water is passed through the condenser, heat will be absorbed to condenser refrigerant which will then flow directly back into the first stage generator. It is possible to generate hot water for space heating and/or domestic hot water at temperatures from 140 to as high as 175 degrees F. The production of hot water can be made available simultaneously with the production of chilled water for air conditioning. When the chiller/heater is producing a minimum of 35% of its refrigeration capacity, it can simultaneously produce as much as 45% of its heating capacity. As cooling requirements increase, the available heating production decreases proportionately. When no refrigeration is needed, the complete fuel input of the chiller/heater can be extracted as hot water at an efficiency of 81%. This compares quite favorably to any commercially available boiler or hot water generator.

The conventional single stage and two-stage series flow absorption chillers are sized for condenser water inlet at 85 degrees F. If, indeed, the condenser water entering temperature increases, then either the capacity of the chiller must be decreased or substantial mechanical damage could ensue. The two-stage parallel flow chiller on the other hand, is designed to operate on condenser water running as high as 92 degrees F. entering. Although the design point is at 85 degrees F., condenser water at 92 degrees F. will not require derating of the machine. It will necessitate a somewhat higher specific fuel input, but the full capacity of the machine is still available at a time when it is needed the most. Also, to effect greater savings, the two-stage parallel flow chiller can be operated with condenser water temperatures ranging down to 69 degrees F. If you consider that every one degree reduction in condenser water temperature below the rated 85 degrees F. results in a 1% efficiency increase, then substantial savings can be gained by using a condenser water reset program to optimize efficiency.

The two-stage parallel flow chiller/heater lends itself to the incorporation of energy management control strategies. As mentioned above, the condenser water temperature can be reset from the design of 85 degrees F. up as high as 92 degrees F. or down as low as 69 degrees F. As the cooler condenser water is available, its use will enhance the energy efficiency of the chiller. The chilled water can also be reset from the design point of 44 degrees F. up to approximately 55 degrees F. without causing any damage whatsoever to the operation of the chiller/heater. The efficiencies will increase at a rate of approximately 1 to 1½% per degree increase in chilled water temperature output. Whether using direct fired, steam, waste gas, etc., the input control mechanism can be modulated by the energy management direct digital control capability to provide infinite positioning for optimum energy efficiency.

Although the standard condenser water flow rate is predicated on a 10 degree Delta T temperature differential (85 degrees F. in - 95 degrees F. out), an 85 degrees F. to 100 degrees F. condenser is available. The use of this expanded condenser rate reduces pumping horsepower as well as piping size by approximately 30%. Other special configurations for particular condenser conditions are also available to help optimize the efficiency of the two-stage parallel flow chiller.

The two-stage parallel flow chiller/heater is very compact in size, usually fitting the same footprint as a similar capacity single stage absorption chiller. The unit is completely assembled at the factory and tested to the specific design conditions specified. The unit is then shipped as one assembly to the jobsite where it is rigged and mounted without need of disassembly and possible intrusion of foreign contaminants.

INSTALLATION

A. The first installation of a two-stage parallel flow chiller/heater in the United States was in New York City at an apartment building at 111 Fifth Avenue in Manhattan. This unit is rated at 500 tons and provides all of the heating and air conditioning for the entire 13-floor building (140,000 sq. ft.). The fuel cost for operating the boiler and steam driven centrifugal chillers for 1979 was $216,000. This compares to the similar period for 1980 using the two-stage parallel flow chiller/heater of $94,238. The net savings was approximately 56%. However when corrected for degree day differential, the actual savings was in excess of 64%. This unit went on line in December of 1979 and has been operating satisfactorily since.

B. Home Federal Savings and Loan Association of San Diego, California installed two 500-ton cogeneration chiller/heaters as part of the cogeneration plant in the 191,000 sq. ft. service center. The complex was completed in 1982 and has successfully provided all of the electricity, heating and air conditioning for the facility since that time. The two-stage chiller/heaters take hot exhaust gas directly from the 800 KW turbine generators and convert it into chilled water or hot water.

C. In June of 1983, St. John's Hospital in Queens, New York started two 400-ton two-stage parallel flow chiller/heaters. These two units supply all of the heating and air conditioning for the 332 bed facility. The original calculations by the engineer indicated a savings in excess of $20,000 per year as compared to a conventional electric centrifugal system. Also, there was a problem with space and because of the compactness and light weight of the two-stage parallel flow chiller/heaters, they were able to be mounted on the roof of the building. This eliminated the necessity of a costly basement boiler room installation.

D. Also in June of 1983, the World Headquarters for the Assembly of God in Springfield, Missouri wanted to eliminate excessive cost involved in the operation of their old single stage absorption chiller. They purchased and installed a 600-ton two-stage parallel flow chiller and have reported savings in excess of 55% over their original boiler absorber setup.

Other chiller/heaters of the same type have been installed in the White & Kirk Building in Amarillo, Texas; Pepsico World Headquarters, Purchase, New York; IBM, Valhala, New York; New York Telephone Company, New York, N.Y.; and many others.

Perhaps the most significant installation of these units is for the Pacific Telephone Company in San Diego, California. Pacific Telephone installed a cogeneration system for their computer center which included three 2100 KW gas turbines and two 1800 KW steam turbines which operated from exhaust heat boilers. They also installed three 450 ton waste heat two-stage parallel flow chillers to operate from the turbine exhaust and three direct fired 450 ton chiller/heaters operating on natural gas. The entire system has been on-line since December of 1982 and has functioned to the complete satisfaction of the Telephone Company and its design engineers. Plans are now in design to use this installation as a guide for other computer power centers.

CONCLUSION

The viability of absorption cooling was thought to be dead in this oil and gas rich region of the Southwest except for those few areas where waste steam was available from some industrial process. However, with the availability of the two-stage parallel flow chiller/heater either direct fired with natural gas or using steam from process boilers, the economics of air conditioning again favor absorption. There is indeed an alternative to the electric air conditioning cost spiral. With a little use of imagination and the proper consideration of the second law of thermodynamics, a designer can reap handsome dividends in the conservation of both economic as well as energy resources by using the two-stage parallel flow chiller/heater.

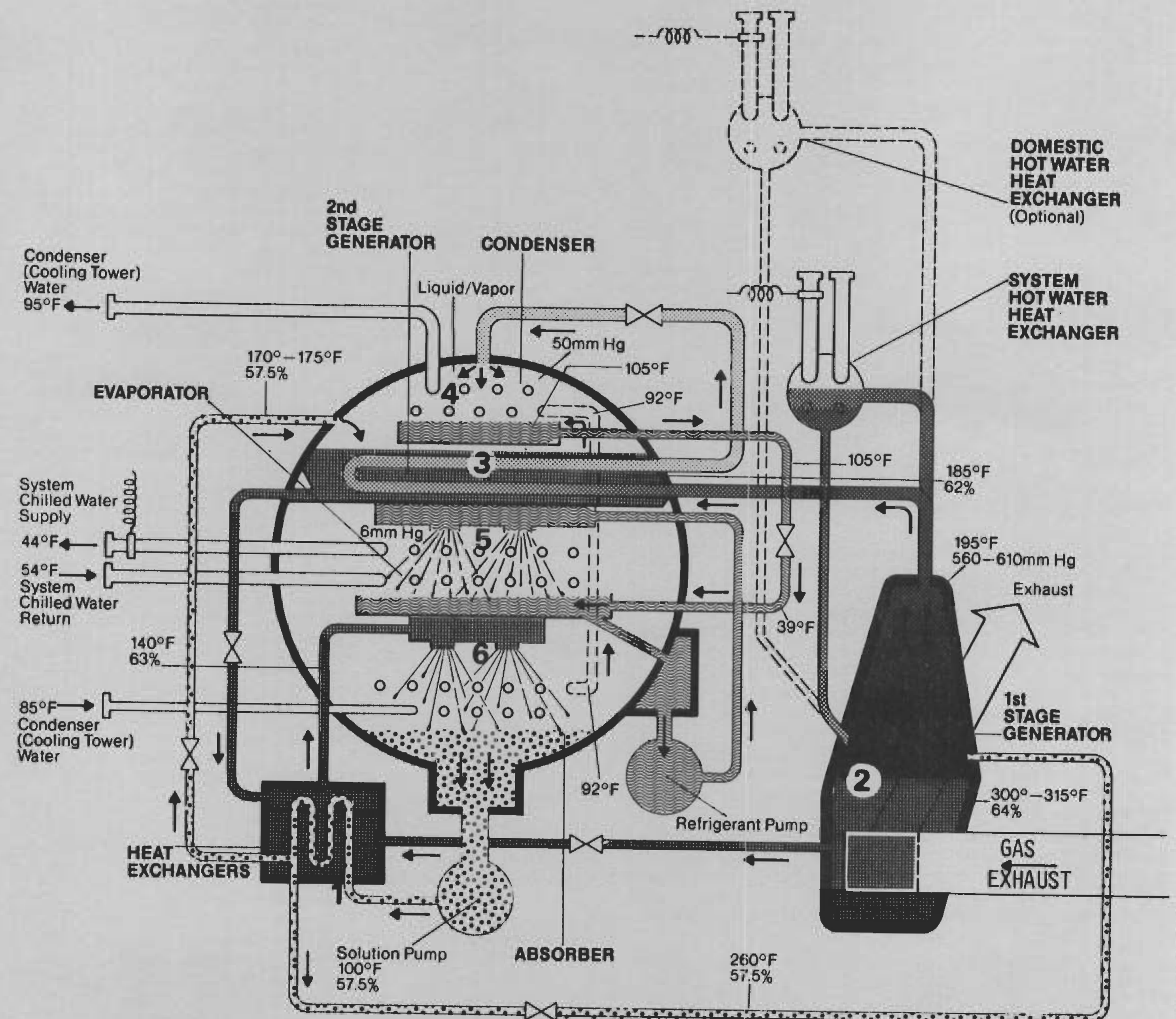

Figure: Schematic diagram of a two-stage parallel flow absorption chiller showing various zones of interest